PLANT AND SOIL RELATIONSHIPS IN TWO HYDROTHERMALLY ALTERED AREAS OF THE GREAT BASIN

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ABSTRACT.— In two areas of hydrothermally altered rocks in the Great Basin, the native vegetation differs in composition and areal cover from unaltered to altered sites on the same geologic formations. Analysis suggests that physical rather than chemical factors may be the cause of the vegetation differences, especially permeability of bedrock, depth and texture of soils, and, possibly, amounts and types of clay minerals present. These characteristics influence the ability of soils to absorb and retain water.

In the East Tintic Mountains, Utah, the soils from argillized or mixed argillized and silicified parent materials have more characteristics associated with dryness and support sparser vegetation and more species especially adapted to dry conditions than do soils from unaltered or silicified parent materials.

In Battle Mountain, Nevada, unaltered areas have greater vegetation cover and have soil depth and texture that are more favorable for plants than do altered areas. Soil pH is higher in altered areas than in unaltered areas.

Where geology is obscured by vegetation, as in the humid regions of the world, vegetation can be used as a clue to the underlying rocks and minerals. Changes in the vegetation along zones of mineralization have been recognized since ancient times and have been well documented in several recent reviews (Malyuga 1964, Rommel 1968, Nesvetailova 1970, Cannon 1971, Brooks 1972). The reasons for the vegetation differences should be found in the physical and chemical properties of the soils that develop on hydrothermally altered, locally mineralized rocks which differ from those of soils that develop on unaltered rocks.

Two previous workers have studied the vegetation in hydrothermally altered areas in the Great Basin of the western United States. Billings (1950) concluded from greenhouse experiments that acid conditions and deficiencies in nitrogen and phosphorus were responsible for the lack of sagebrush on altered sites in the Virginia Range near Virginia City, Nevada. Salisbury (1954, 1964) performed similar experiments at Big Rock Candy Mountain, Utah, and concluded that nutrients in acid soils (pH 3.3) were chemically bound by iron and aluminum and therefore were unavailable to plants. These studies describe extreme states, in which the soil pH is very low and the vegetation is drastically different from that on nearby unaltered rocks. In many other hydrothermally altered areas, altered soils have pH ranges comparable with those of unaltered soils, and vegetation differences are more subtle.

The most striking vegetation differences in the study areas described in this report are on sites of intermediate alteration intensity, whereas the unaltered and the most intensely altered sites have more similar vegetation. Since intensely altered sites have been subjected to more leaching than intermediate sites, nutrient deficiencies and toxicities would seem to be ruled out as likely causes of the vegetation differences. The most common limiting factor of plant growth in arid and semiarid areas is water. Infiltration and water retention are closely related to soil depth, soil texture, i.e., the distribution of different-sized particles in the soil, and the type of clay minerals in the soil (Black 1968, Foth and Turk 1972). For the present study, the hypothesis of drier soil conditions in areas of intermediate alteration intensity was tested by examining soil characteristics on altered and unaltered sites and by comparing the vegetation distribution with that found by other workers in similar terrain.

STUDY AREAS

Two study areas in Utah and Nevada were chosen to coincide with areas of ongoing re-

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search in the use of remote sensing techniques to identify hydrothermally altered rocks. The Utah study area has been used as a test site for mapping hydrothermally altered rocks from high altitude and satellite imagery (Rowan and Abrams 1978a, b, Rowan and Kahle 1982). Krohn et al. (1978) used Landsat imagery to detect hydrothermally altered rocks at the Nevada study area. Both areas were found to be at the limit beyond which limonitic hydrothermally altered rocks could not be detected through the plant cover by the remote sensing techniques used. For this reason they were considered ideal sites for devising a method to detect altered rocks by using differences in vegetation.

Emplacement of intrusive bodies during the Tertiary resulted in alteration of host rocks to form several types of altered rocks. Argillic and silicic alteration are the most common types in the study areas, and are the only types included in this study. In general, the acidic hydrothermal fluids followed faults and fractures in the rocks. The mineralizing fluids changed in composition away from the source, which resulted in a gradual decrease in alteration along the path of the fluid. Another change that took place outward from the path resulted in a gradation of alteration away from the conduit. These changes produced a zonation of altered rocks. Silicified rocks are closest to the conduit and the source and are surrounded by argillized rocks, beyond which is an area of gradual transition to unaltered rock. Widths of zones vary and can range from a few meters to several hundred meters (Lovering 1949, 1960, Lovering and Shepard 1959).

Degrees of alteration are reflected in the different clay minerals produced. Moderate alteration and supergene weathering under mild conditions favored the formation of montmorillonite. More intense alteration and a more acidic weathering environment resulted in the formation of kaolinite. In addition, supergene weathering resulted in the conversion of ferrous iron to limonite, causing the weathering environment to be more acidic in altered areas than in unaltered areas (Lovering 1949).

The study includes unaltered, argillized, and silicified sites. The argillized rocks are bleached, limonite stained, and friable. They are formed by cation leaching, addition of water, and formation of clays. Kaolinite, mixed-layer clays, and montmorillonite are present. Kaolinite decreases away from the conduit. Initial porosity is greater in the altered rock than in the host rock. In the Utah study area, however, gravity compacts the argillized rocks, causing the pores to close, and a nearly impermeable rock results (H. T. Morris, oral comm. 1979). Silicified rocks are limonite stained and very hard, composed largely of silica, and containing some kaolinite and mixed-layer clays. Porosity remains higher than in the fresh and argillized rock because of the rigidity of the matrix surrounding the pores (H. T. Morris, oral comm., 1979). The SiO_2 content of silicified rocks can be as high as 90–95 percent, making the original texture of the rock difficult or impossible to determine.

East Tintic Mountains, Utah

The East Tintic Mountains are located in Juab and Utah counties, west central Utah, near the eastern edge of the Great Basin (Fig. 1). The area is classified as semiarid desert, having an average annual precipitation of about 30 cm. The range is made up of Paleozoic sedimentary rocks partly overlain by Tertiary volcanic rocks. The Tertiary rocks include quartz latite and latite tuffs and flows. Intrusive bodies associated with the tuffs and flows are numerous, though not large, and range from monzonite to quartz monzonite. The Paleozoic rocks were extensively folded and faulted prior to the Tertiary volcanism (Morris 1957, 1964a, Morris and Lovering 1961, 1979, Lovering 1960).

The study was confined to two Tertiary units, the Packard Quartz Latite and the overlying Laguna Springs Volcanic Group. The Packard Quartz Latite consists of quartz latite tuffs and flows that contain phenocrysts of andesine, sanidine, quartz, and biotite in a fine-grained to glassy groundmass (Morris and Lovering 1961).

The Laguna Springs Volcanic Group consists of latite tuffs and flows. The tuffaceous member ranges from fine to coarse grained and in some areas is agglomeratic. The flow is a medium- to coarse-grained latite that contains phenocrysts of orthoclase, plagio-

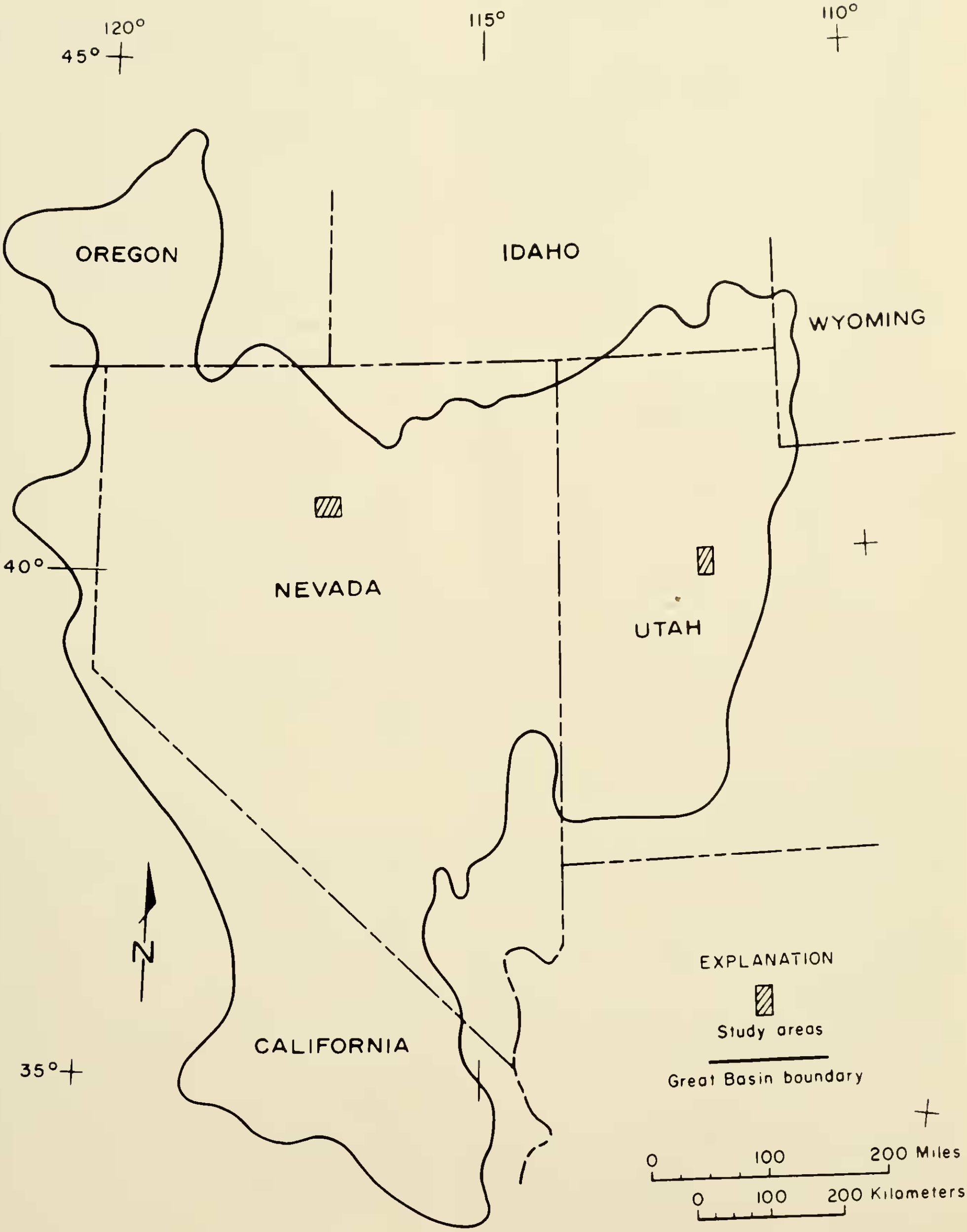

Fig. 1. Location of study areas in the Great Basin.

clase, hornblende, biotite, augite, magnetite, and quartz (Morris and Lovering 1961).

Battle Mountain, Nevada

Battle Mountain is located in Humboldt and Lander counties, north central Nevada (Fig. 1). The climate is arid, having about 15 cm average annual precipitation. The area is made up of Cambrian to Tertiary sedimentary and volcanic rocks. The pre-Tertiary rocks have been intruded by early Tertiary stocks, sills, and dikes. The geology of Battle Mountain is further complicated by its position along the Roberts Mountain and Golconda thrust zones.

Alteration at Battle Mountain took place at various times throughout the Paleozoic and Mesozoic, and most recently during the Tertiary. Potassic, argillic, and silicic alteration are present but are difficult to distinguish from each other in the field; for this report, rocks are categorized only as unaltered or altered (Roberts and Arnold 1965, Roberts et al. 1971, Theodore and Roberts 1971, Shawe and Stewart 1976, Silberman et al. 1976).

Three formations were chosen for the study. The Devonian Scott Canyon Formation is composed predominantly of chert, argillite, and greenstone with minor shale, limestone, and orthoquartzite. As the clastic content increases, the chert grades into argillite. Recrystallization of Scott Canyon chert by hydrothermal alteration resulted in an altered chert difficult to distinguish in the field from unaltered chert except for the presence of small amounts of altered argillite (Theodore and Blake 1975).

The Late Cambrian Harmony Formation is composed of feldspathic sandstone interbedded with shale and limestone. The sandstone is medium grained, subangular to subrounded, and poorly sorted. The formation is highly susceptible to alteration due to its texture and fine fracture patterns. Many of the mineralized areas were also enriched by supergene alteration (Theodore and Blake 1975, Suczek 1977).

The Pumpernickel Formation is Early Pennsylvanian to Early Permian in age. It consists of chert and argillite with minor shale, greenstone, limestone, sandstone, and conglomerate. Alteration resulted in recrystallization to quartzose hornfels. In addition, some silica was added and most oxides were decreased (Roberts 1964, Theodore and Blake 1975).

Vegetation

The vegetation of the study areas is included in the sagebrush and pinyon-juniper zones described by Billings (1951), Blackburn et al. (1968, 1969), Cronquist et al. (1972), Tueller (1975), Young et al. (1976, 1977), and MacMahon (1979). *Artemisia tridentata* (big sagebrush), commonly with *Chrysothamnus nauseosus* (rabbitbrush), *Purshia tridentata* (antelopebrush), grasses, and forbs, inhabits wide valleys and lower slopes, and occurs more sparsely within the pinyon-juniper woodland. *Juniperus osteosperma* (Utah juniper) is the most prevalent tree, found in stands having little undergrowth or scattered among the shrub communities. *Pinus monophylla* (single-leaf pinyon pine) is a common associate. Stream valleys and moist north-facing slopes contain a dense growth of *Acer grandidentatum* (bigtooth maple), *Prunus virginiana* (choke cherry), *Symphoricarpos oreophilus* (snowberry), and *Amelanchier utahensis* (shadbush). Many altered areas support a sparse and low flora, often including *Artemisia nova* (black sagebrush), *Petradoria pumila* (rock goldenrod), and other low matted shrubs and herbs. In addition, several halophytic species from the surrounding bajada slopes are found in altered areas in Battle Mountain.

Nomenclature for Utah follows Welsh and Moore (1973); that for Nevada follows Munz (1968).

METHODS

Sites for sampling of vegetation and soils were chosen from geologic and alteration maps. To minimize variables, slopes chosen ranged from 1,500 to 2,100 m in altitude, were south facing (azimuth 135° to 225°), and inclined between 12° and 20°. Side slopes and spurs were chosen rather than coves to minimize drainage-catchment differences, and slopes containing springs were avoided. In the field, the sampling sites were further limited to those near roads and relatively undisturbed (e.g., not recently chained or burned).

Vegetation Sampling

A floristic list for each site was made, including forbs and grasses. Unfortunately, the lists are not complete, because each study area could not be visited during each part of the growing season, and the vegetation data presented here do not include forbs. However, shrubs and trees can be used to indicate soil and water conditions, as well as lithologic variations (e.g., Chikishev 1965).

Areal cover of vegetation was measured by using a modification of the line-interception method (Canfield 1941). Two 15 m tapes were stretched at right angles, one along the contour. The intercept of each species along the tapes was measured to the nearest centimeter, and the percent cover was calculated. Dead organic matter (standing dead and litter) was measured as "mulch." For each slope, fifteen 30-meter transects were measured and averaged to give a representative vegetation sample for each site. Total vegetation cover is the percentage of ground covered by trees, shrubs, grasses, or mulch.

Soil Sampling

Soil samples were taken from the same slopes on which vegetation was measured. Four sites on each alteration type in each geologic formation were sampled at depths of 20 to 60 cm. Rocks larger than about 1.0 cm were removed from samples at the time of collection. Because of the difficulty of augering such dry, rocky soils, holes were dug with a small shovel as deeply as possible. As a result, measurements of pore space or bulk density were not possible.

Silicification of flow and tuff units obscures the original texture so that these units are difficult to distinguish from one another in the field; also they would be expected to form identical soils because of their similar initial chemical composition. For this reason, the silicified Laguna Springs latite soil samples used in the summaries are the same for flow and tuff examples.

Soil pH was measured by a glass electrode pH meter on a 1:1 soil-water suspension. Cation exchange capacity (CEC) was measured by the modified barium chloride-triethanolamine procedure (Chapman and Pratt 1961), using a flame photometer.

Clay minerals were identified by X-ray diffraction analysis. Oriented slides were run untreated, after heating to 350 C and 500 C, and after treatment with ethylene glycol. Minerals having (001) peaks at 7.1 Å that disappeared after hearing to 500 C were identified as kaolinite-group. Illite-group minerals were identified as those having (001) peaks at 10.2 Å. Minerals having (001) reflections that expanded from 14 Å on untreated samples to 15 Å to 17 Å on samples treated with ethylene glycol were called mixed-layer illite-montmorillonites, and the percentage of expandable layers was estimated from the relative peak intensities. In the absence of other important peaks, relative proportions of the three clay groups could be estimated from the peak intensities (M. Hess, oral comm., 1977).

Particle size analysis was done by the hydrometer method and a series of sieves, using methods adapted from ASTM (1978) and Lambe (1951). Organic matter was not removed. Weighed samples were soaked overnight in sodium metaphosphate and sonified to aid dispersion. Soils were separated into the following fractions: clay (<2 μ), silt (2–50 μ), fine sand (50–250 μ) and coarse sand (250–1,000 μ).

Statistical Analysis

The Kruskal-Wallis test for central tendency (Gibbons 1976) was used to test the null hypothesis that there were no significant differences in the areal cover of vegetation in the East Tintic Mountains. Areal cover data for Battle Mountain were analyzed by using the Mann-Whitney-Wilcoxon test (Gibbons 1976). Different tests were used because of the different numbers of independent variables in the two study areas. Vegetation and soil differences were tested only within, and not between, the two study areas. Nonparametric tests were chosen in preference to the corresponding parametric tests because of small sample sizes and unknown distributions.

A binary discriminant analysis (Strahler 1978a, b) was used to compare affinity of plant species for rock formation and alteration type, resulting in a list of plant species for each type that best describes its difference from the other types. This is not a floristic list nor a list of dominant species; only those species strongly correlated with rock and alteration type ($p = 0.01$) are listed. In this test, each vegetation sample is entered separately rather than averaged to give a composite sample for each rock and alteration type. Frequency, rather than areal cover, is the variable used in this analysis.

Results

East Tintic Mountains, Utah

The two most common species on the Packard Quartz Latite areas, *Artemisia tridentata* and *Purshia tridentata,* have higher areal cover measurements on unaltered and silicified sites than on argillized sites (Table 1). *Chrysothamnus nauseosus* and *Ephedra viridis* are found only in unaltered and silicified areas. Grasses and mulch also have higher areal cover on unaltered and silicified sites than on argillized sites. In contrast, the cover of *Juniperus osteosperma* is higher on the argillized sites. This results in a high total vegetation measurement, even though there is actually substantial bare ground under and between the trees in argillized areas. With the exception of *J. osteosperma*, each species has lower areal cover on argillized than on unaltered and silicified sites.

The samples from the latite flow sites of the Laguna Springs Volcanic Group also show that samples from unaltered and silicified areas have higher shrub and nontree subtotals than do the samples from argillized sites (Table 1). Grasses and mulch have lower areal cover in argillized areas. An important difference is the presence of *Artemisia nova* only on the argillized sites.

The argillized samples from the Laguna Springs latite tuff (Table 1) have the lowest shrub and nontree subtotals and the lowest *Artemisia tridentata, Purshia tridentata,* grasses, and mulch. *Artemisia nova* occurs only on argillized sites. A greater variety of herbaceous species was observed in argillized areas than in unaltered and silicified areas on both tuff and flow, although forbs, as stated above, are not included in the vegetation summaries.

The statistically significant differences in shrub cover, nontree cover, and tree cover in

Table 1. Vegetation cover (in percent) for the East Tintic Mountains study areas. U, Unaltered. A, Argillized. S, Silicified.

	Packard Quartz Latite			Laguna Springs Volcanic Group				
				Flows		Tuffs		Tuffs and flows undifferentiated
	U	A	S	U	A	U	A	S
Artemisia tridentata	8.23	.81	14.68	16.20	9.19	12.86	7.09	9.28
A. nova					1.42		1.71	
Purshia tridentata	1.61	.49	6.22	.21	.26	5.74	.63	2.64
Chrysothamnus nauseosus	.08		.11		.78	.98		.17
C. viscidiflorus				.17			.05	
Ephedra viridis	1.50		.14					
Opuntia sp.			.08	.12			.03	
Gutierrezia sarothrae		.08	.01		.07			.50
Tetradymia sp.							.04	.02
Arenaria kingii			.02				1.18	.10
Petradoria pumila		.07	1.01				1.25	.05
Cercocarpus montanus			.31					
Subtotal	11.42	1.45	22.58	16.70	11.72	19.58	11.98	12.76
Grasses	1.96	.06	1.17	2.02	1.28	4.03	1.60	3.71
Mulch	8.18	3.30	9.58	11.74	7.85	14.62	6.85	10.85
Subtotal	10.14	3.36	10.75	13.76	9.13	18.65	8.45	14.56
Nontree subtotal	21.56	4.81	33.33	30.46	20.85	38.23	20.43	27.32
Juniperus osteosperma	6.90	29.34	5.18	5.76	6.25		4.32	1.64
Pinus monophylla	2.47	.29	2.99	2.75	1.53		1.99	
Tree subtotal	9.37	29.63	8.17	8.51	7.78		6.31	1.64
Total vegetation	30.93	34.44	41.50	38.97	28.63	38.23	26.74	28.96
Standard deviation	± 10.5	± 15.9	± 12.7	± 9.1	± 13.5	± 8.4	± 11.5	± 11.6
Number of samples	15	15	15	15	15	15	15	30

Table 2. Significant differences in vegetation on different alteration types using the Kruskal-Wallis test on the East Tintic Mountains data.

	Total vegetation	Shrub cover	Shrubs grasses mulch	Tree cover
Packard Quartz Latite				
Unaltered vs. argillized	—	°	°	°
Unaltered vs. silicified	°	—	—	—
Argillized vs. silicified	—	°	°	°
Laguna Springs Volcanic Group: Flows				
Unaltered vs. argillized	°	°	°	—
Unaltered vs. silicified	°	—	—	—
Argillized vs. silicified	—	—	°	—
Laguna Springs Volcanic Group: Tuffs				
Unaltered vs. argillized	°	°	°	—
Unaltered vs. silicified	—	°	°	°
Argillized vs. silicified	—	—	°	—

°Significantly different at $p < 0.15$

samples from the Packard Quartz Latite sites occur between unaltered and argillized samples and between silicified and argillized samples (Table 2). That is, the argillized samples are significantly different from both unaltered and silicified samples, whereas unaltered and silicified samples differ from each other only in total vegetation cover.

The Laguna Springs flow data show significant differences between unaltered and argillized samples in total vegetation, shrub cover, and nontree cover (Table 2). The argillized and silicified samples are significantly different only in the nontree measurements.

In the Laguna Springs tuff results, the unaltered and argillized samples differ significantly in total cover, shrub cover, and nontree cover, and the argillized and silicified samples differ in nontree cover (Table 2). In addition unaltered and silicified samples differ significantly in all but total vegetation cover.

Thus, the vegetation is similar in unaltered and silicified areas but different in argillized areas; on the Laguna Springs Volcanic Group, silicified areas are more like argillized than like unaltered areas.

The binary discriminant analysis results for the Packard Quartz Latite data (Table 3) show that unaltered areas are characterized by *Artemisia tridentata* and *Ephedra viridis*, argillized areas by *Juniperus osteosperma*, and silicified areas by *Purshia tridentata*. The correlation of *A. nova* with argillized flow and tuff is notable in the Laguna Springs data.

Soils in unaltered areas were dug to depths of 25–35 cm. A thin organic layer alternates with pebble- to cobble-sized angular float.

Table 3. Binary discriminant analysis results for East Tintic Mountains. Species listed are significantly correlated with rock and alteration type at $p = 0.01$. U, Unaltered. A, Argillized. S, Silicified. +, $d \geq 2.0$. –, $d \leq -2.0$.

	Packard Quartz Latite			Laguna Springs Volcanic Group				
	U	A	S	U	A	U	A	S
Artemisia tridentata	+	–						
Ephedra viridis	+	–						
Juniperus osteosperma		+	–	+		–		+
A. nova					+		+	
Purshia tridentata		–	+	–	–	+	–	+
Chrysothamnus nauseosus						+	–	
C. viscidiflorus								–
Gutierrezia sarothrae				–		–	–	+
Arenaria kingii						–	+	+
Petradoria pumila								+
Haplopappus acaulis							+	

The rock fragments increase in size as depth increases. The soil is light brown (Munsell color 7.5YR5/4) (Munsell Color Company 1969) to grayish brown (7.5YR4/2). Roots decrease in frequency as depth increases and penetrate crevices in the rock beyond the depth possible to dig by hand.

Soils in argillized areas are shallower (about 15 cm) and range in color from moderate brown (7 5YR4/4) to light yellowish or rusty brown (10YR7/4). The organic layer is absent or thinner than in unaltered areas. Pebble- to boulder-sized bleached and limonite coated rock fragments cover the top layer of soil and are profuse at all levels. At the deepest level dug, rocks are friable and roots are few.

Soils in silicified areas are nearly as deep as those in unaltered areas, and color is similar. Bleached rock fragments occur at the surface. Finer particles are found deeper than in soils on unaltered areas, and roots are profuse in lower parts of the soil profile.

Soil pH ranges from 6.6 to 7.7 (Table 4). No significant differences were found between soils on different rock or alteration type. Cation exchange capacity (CEC) ranged from 17 to 43 Me/100g (Table 4). In general, soils on Packard Quartz Latite areas have higher CEC than soils on the Laguna Springs Volcanic Group, except in silicified areas. Using the Spearman coefficient of correlation (Gibbons 1976), the CEC was found to be weakly positively correlated with the total clay content (r = 0.413). CEC is strongly negatively correlated (r = -0.780) with the amount of kaolinite in the soil and positively correlated (r = 0.630) with the amount of montmorillonite. However, the lack of significant differences between soils of different alteration types seems to indicate that, although the tests were done with reasonable accuracy, the CEC and clay content are too variable within soils of a single alteration type to be diagnostic of it.

Physical analysis of the soil samples includes particle size analysis for texture and X-ray diffraction analysis for identification of clay minerals. In the Packard Quartz Latite samples, clay content is about the same on all three alteration types (Table 4). Silt content, however, is higher and coarse sand content is lower in silicified areas than in unaltered and argillized areas.

In the samples from the latite flow in the Laguna Springs Volcanic Group, the unaltered soils have the most silt and the least coarse sand, argillized soils have the least silt and the most coarse sand, and silicified soils have intermediate amounts of each. In the sites on the tuffs, the argillized and silicified samples are similar, and the unaltered soils have less silt and more coarse sand.

Because clay is formed in the alteration process, a higher clay content would be expected in altered, particularly in argillized, areas. The small clay differences recorded in the samples suggest that dispersion was not complete in all tests.

The predominant types of clay minerals in the samples vary (Table 4). The standard de-

Table 4. pH, cation exchange capacity (CEC), particle size distribution and relative clay content for East Tintic Mountains soils. U, Unaltered. A, Argillized. S, Silicified.

	Packard Quartz Latite			Laguna Springs Volcanic Group				
	U	A	S	U		A		S
pH	6.8–7.7	6.9–7.6	6.7–7.6	6.7–7.2		6.6–7.5		6.7–7.4
CEC (Me/100g)	36 ±5	37 ±6	25 ±8	28 ±4		27 ±3		31 ±3
				Flows		Tuffs		
Particle size (percent)				U	A	U	A	S
Coarse sand	30 ±12	29 ±3	8 ±6	9 ±1	18 ±3	23 ±3	12 ±4	11 ±6
Fine sand	27 ±5	24 ±3	28 ±5	31 ±5	27 ±8	27 ±3	31 ±6	30 ±4
Silt	16 ±5	19 ±6	36 ±5	35 ±3	27 ±3	23 ±7	31 ±3	30 ±6
Clay	27 ±5	28 ±3	28 ±2	25 ±3	28 ±7	27 ±2	26 ±4	29 ±5
Relative clay content (percent)								
Kaolinite	14	25	40	27	21	42	41	33
Illite	47	49	44	44	67	55	56	61
Mixed-layer	50	33	24	24	24	9	7	11
Montmorillonite	39	26	16	14	12	4	3	6

viations of the X-ray data averages are large, so that these data can only be used to make rough comparisons from one alteration type to another. In the samples from the Packard Quartz Latite, the unaltered samples have the least kaolinite and the most mixed-layer clay and montmorillonite. Soils of silicified areas have the most kaolinite and the least mixed-layer clay and montmorillonite. Soils of argillized areas are intermediate between the two but have the greatest amount of illite.

The Laguna Springs latite samples show fewer differences in clay type (Table 4). All the soils contain large amounts of illite, less kaolinite, and small amounts of montmorillonite.

The soil characteristics of silicified areas resemble those of argillized latite areas in the Laguna Springs Volcanic Group. Following a suggestion of R. P. Ashley (oral comm., 1978), the silicified areas were examined and found to contain large amounts of argillized float around the silicified outcrops. This indicates that the soils from silicified areas are mixed with argillized material, resulting in smaller differences in soils and vegetation on the two alteration types than would be expected. The amount of argillized float on silicified areas of the Packard Quartz Latite is small, so that soils and vegetation differences are large.

Battle Mountain, Nevada

The vegetation patterns in the Battle Mountain study area show differences in composition and areal cover from unaltered to altered sites (Table 5). The altered areas have lower total vegetation cover on all three formations, and, except on the Harmony Formation, more variety of species is found in altered areas. Shrub cover is lower on altered sites of the Pumpernickel and Scott Canyon formations than on unaltered sites but remains nearly the same on the Harmony Formation; areal cover of grasses and mulch is higher on unaltered than on altered sites. Areal cover of *Artemisia tridentata* is higher on unaltered than on altered sites on all three formations and is absent on altered Harmony Formation. *Chrysothamnus nauseosus* is more likely to be found on unaltered sites, and *C. viscidiflorus* on altered sites. *Artemisia nova* rather than *A. tridentata* is found on the altered Harmony Formation.

Shrub cover and total vegetation cover are significantly different on unaltered and altered areas of the Pumpernickel and Scott Canyon formations (Table 6). On the Harmony Formation, the shrub cover is similar on unaltered and altered sites, but the greater amount of mulch on unaltered sites makes the total vegetation cover significantly different. Differences in vegetation cover between

Table 5. Vegetation cover (in percent) for the Battle Mountain study areas. U, Unaltered. A, Altered.

	Pumpernickel Formation		Scott Canyon Formation		Harmony Formation	
	U	A	U	A	U	A
Artemisia tridentata	15.9	3.5	15.2	11.1	19.1	
A. nova						18.8
Purshia tridentata	4.4					
Chrysothamnus nauseosus	.4		.2		.5	1.0
C. viscidiflorus		1.9	.2	.5		
Tetradymia sp.		1.8	1.5	1.4	.3	
Atriplex confertifolia		1.6	trace	.4		.1
Ephedra nevadensis		.3		0.9		
Peucephyllum schottii		trace		.3		
Subtotal	20.7	9.1	17.1	14.6	19.9	19.9
Grasses	2.6	4.5	2.0	1.7	2.2	1.1
Mulch	10.9	3.8	9.1	9.1	10.0	2.6
Subtotal	13.5	8.3	11.1	10.8	12.2	3.7
Total Vegetation	34.2	17.4	28.2	25.4	32.1	23.6
Standard deviation	± 7.8	± 4.4	± 6.9	± 4.3	± 4.6	± 6.7
Number of samples	15	15	15	15	15	15

Table 6. Significant differences in vegetation on different alteration types using the Mann-Whitney-Wilcoxon test on the Battle Mountain data.

	Total vegetation	Shrub cover
Pumpernickel Formation		
Unaltered vs. altered	°	°
Scott Canyon Formation		
Unaltered vs. altered	°	°
Harmony Formation		
Unaltered vs. altered	°	—

°Significantly different at $p < 0.15$

unaltered and altered sites are greater than those on different rock types.

Binary discriminant analysis results (Table 7) show that unaltered Pumpernickel Formation sites are characterized by *Artemisia tridentata* and *Purshia tridentata,* altered sites by *Atriplex confertifolia, Chrysothamnus viscidiflorus,* and *Tetradymia* sp. (Table 3). The altered Scott Canyon Formation sites contain *Peucephyllum schottii, Chrysothamnus viscidiflorus,* and *Ephedra nevadensis,* whereas only *Artemisia tridentata* is significantly correlated with the unaltered sites. *Artemisia tridentata* is characteristic of unaltered Harmony Formation and *A. nova,* of altered sites.

The pH of unaltered Battle Mountain soils was lower than that of altered soils in all three formations (Table 8). Soil depths were greatest (35 cm) in unaltered Pumpernickel chert and Scott Canyon chert soils. Depths of altered soils and unaltered Harmony sandstone soil averaged 20–25 cm.

The particle size distribution analysis results show similar patterns for all three formations (Table 8). Soils of unaltered areas are coarser than those of altered areas. The silt difference is greatest in the Harmony Formation, and the coarse sand difference is greatest in the Scott Canyon Formation. As in the Utah study area, the absence of the expected higher clay content in altered areas suggests that the clays may not have dispersed completely.

The soils in altered areas of all three formations have more kaolinite and less illite than those of unaltered areas (Table 8). In addition, the unaltered Scott Canyon soils contain montmorillonite. Again, differences are not large, particularly in the Pumpernickel soils, and the standard deviations are high. Consequently, only general comparisons can be made between soils of unaltered and altered areas.

The altered sites on all three formations are lower in altitude than the corresponding unaltered sites. This factor, plus the presence of *Atriplex confertifolia* and the higher pH on the altered sites, suggests that the vegetation may be influenced by increased salinity as well as by a factor in the alteration process.

Discussion

In the East Tintic Mountains study area, total vegetation cover is lower in argillized areas than in unaltered and silicified areas, except on the argillized Packard Quartz Latite, where large numbers of *Juniperus osteosperma* are found. All other species have lower areal cover on the argillized Packard areas, and the ground is relatively bare under and around the trees. In addition, the composition of the plant communities varies with rock type and alteration history. On unaltered and silicified areas are large amounts of mulch, *Artemisia tridentata, Purshia tridentata,* and *Ephedra viridis.* Argillized areas, in contrast, contain mostly *Juniperus osteosperma* and a very few shrubs.

Table 7. Binary discriminant analysis results for Battle Mountain vegetation data. Species listed are significantly correlated with rock and alteration type at $p = 0.01$. U, Unaltered. A, Altered. +, $d \geq 2.0$. –, $d \leq -2.0$.

	Pumpernickel		Scott Canyon		Harmony	
	U	A	U	A	U	A
Artemisia tridentata	+		+	+	+	–
A. nova						+
Purshia tridentata	+					
Chrysothamnus nauseosus		–		–		+
C. viscidiflorus	–	+		+	–	–
Atriplex confertifolia		+				
Tetradymia sp.	–	+		+		–
Peucephyllum schottii				+		
Ephedra nevadensis				+		

Table 8. pH, particle size distribution and relative clay content for Battle Mountain soils. U, Unaltered. A, Altered.

	Pumpernickel Formation		Scott Canyon Formation		Harmony Formation	
	U	A	U	A	U	A
pH	6.8–7.3	7.6–7.9	6.8–7.3	7.2–7.9	6.7–7.3	6.9–7.8
Particle size (percent)						
Coarse sand	7 ±1	4 ±2	15 ±2	5 ±3	11 ±3	8 ±2
Fine sand	17 ±2	18 ±1	24 ±2	24 ±4	23 ±4	23 ±4
Silt	51 ±2	54 ±3	34 ±2	38 ±6	38 ±5	49 ±3
Clay	25 ±3	24 ±3	27 ±6	31 ±1	28 ±6	20 ±6
Relative clay content (percent)						
Kaolinite	23	28	20	49	17	29
Illite	77	72	70	51	83	71
Montmorillonite			5	0		

On the latite of the Laguna Springs Volcanic Group, vegetation differences are large between unaltered and argillized sites, but small between silicified sites and argillized sites. The vegetation on unaltered sites is composed largely of *Artemisia tridentata* and *Purshia tridentata*, whereas the argillized areas contain *A. nova* and a wide variety of minor shrubs.

In areal cover and in composition of vegetation the silicified areas of the Laguna Springs Volcanic Group fall between argillized areas and unaltered areas. The areas labeled 'silicified' contain a mixture of silicified and argillized float, which accounts for the similarity of soils and vegetation on argillized and silicified sites.

In the Battle Mountain study area, shrub cover and total vegetation cover are greater in unaltered areas than in altered areas; *Artemisia tridentata* is the most common shrub in all areas except on altered Harmony Formation, where it is replaced by *A. nova*. *Atriplex confertifolia* occurs on altered sites.

Several soil parameters were measured in an attempt to explain the causes of the vegetation patterns. The hypothesis of low nutrient levels to explain the low vegetation cover in some altered areas was discarded because of high vegetation cover measurements in the most highly altered, leached areas. Physical and chemical analyses of the soils include measurements of pH, cation exchange capacity, particle size distribution, and X-ray diffraction for identification of clay minerals. Although not quantitatively significant, some relationships seem to exist between areal cover of vegetation and soil characteristics. The hypothesis that water is the most important limiting factor in plant growth is supported by the following reasons and comparisons:

1. *Juniperus osteosperma* and *Artemisia nova*, which are found on argillized Packard Quartz Latite and on the argillized Laguna Springs Volcanic Group and altered Harmony Formation, respectively, are known to occur in the drier habitats in the Great Basin (Blackburn et al. 1968, 1969, Cronquist et al. 1972, Zamora and Tueller 1973, Vasek and Thorne 1977).
2. The high percentage of bare ground, around and under the trees on the argillized Packard Quartz Latite and between the low shrubs on the argillized Laguna Springs Volcanic Group and altered Scott Canyon and Pumpernickel Formations, results in high runoff and low infiltration of rainfall.
3. Although soil was not dug to bedrock due to the difficulty of digging, the soil appeared to be shallower in argillized areas and mixed argillized and silicified areas than in unaltered and silicified areas in the East Tintic Mountains, and shallower in the altered Battle Mountain areas than in the unaltered areas, except on the Harmony Formation.
4. Fractured unaltered and silicified bedrock allows greater infiltration of rainfall than does the highly compacted argillized bedrock in the East Tintic Mountains.
5. The argillized areas are low in mixed-layer clays and montmorillonite, which would retain more moisture. The presence of montmorillonite on the unaltered Scott Canyon Formation, Packard Quartz Latite, and Laguna Springs Volcanic Group may in-

crease water capacity. However, total clay content is probably more important than type of clay in areas that have a mixture of clay types.

6. The other major difference between unaltered and altered soils in Battle Mountain, the higher pH of altered soils, can account for the presence of salt-loving plants such as *Atriplex confertifolia* but does not explain the decrease in vegetation cover on altered sites, because nearby areas that contain halophytic communities have quite dense vegetation.

Conclusions

Vegetation patterns of areal cover and distribution of species are related to the distribution of hydrothermally altered and unaltered rocks in two areas within the Great Basin. Several factors, including bare ground, shallow soil, impermeable rock, soil texture, and, possibly, clay composition in some areas appear related to low vegetation cover in argillized areas, and suggest that water may be limiting in these areas. The results are consistent with those of other workers in the Great Basin. This type of information is needed for the development of techniques for using vegetation as an aid to prospecting in vegetated regions.

Acknowledgments

The authors are grateful to Drs. J. T. Hack and F. A. Branson of the U.S. Geological Survey for critical reviews of the manuscript.

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